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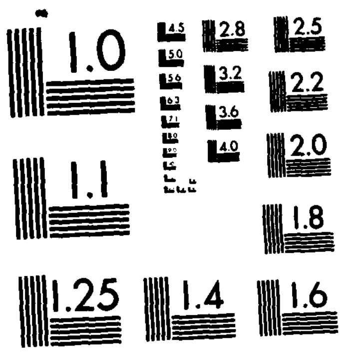
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MEMORANDUM REPORT BRL-MR-3474

EXPERIMENTAL DESIGN AND ANALYSIS FOR THE FIST FORCE DEVELOPMENT TESTING AND EXPERIMENTATION II

Jock O. Grynovicki
Jill H. Smith

October 1985

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
MEMORANDUM REPORT BRL-MR-3474

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
EXPERIMENTAL DESIGN AND ANALYSIS FOR THE FIST FORCE DEVELOPMENT TESTING AND EXPERIMENTATION II

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Jock O. Grynovicki
Jill H. Smith

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
US Army Ballistic Research Laboratory
ATTN: SLCBR-SE
Aberdeen Proving Ground, MD 21005-5066

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

12. REPORT DATE
October 1985

13. NUMBER OF PAGES
44

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Fire Support Team Headquarters (FIST HQ), Message Collection and Reduction System, Microprocessor Based Modems (Bit Box), Cluster Analysis, Fist Digital Message Device (DMD), Analysis of Variance (ANOVA), Force Development Testing and Experimentation (FDT&E), Ground/Vehicle Laser Location Designator (G/VLLD)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In April and May 1984, The Field Artillery Board, Ft. Sill, OK conducted a Force Development Test and Experimentation (FDT&E) of the Fire Support Team (FIST) Concept at Ft. Riley, KS. The purpose of the FDT&E was to test and evaluate the effectiveness of the FIST HQ equipped with FIST vehicles and digital communications equipment under various tactical configurations, selected modes of operation and personnel shortages. Although traditional manual data collection methods employing human observers was used to record

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test data, a new automatic data recording technique based on the Artillery Control Environment (ACE) technology was used for the first time in the field. Personnel from the Ballistic Research Laboratory (BRL) assisted in the experimental design, and were responsible for designing, coding and testing the computer software used in the data collection and reduction system.

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I. INTRODUCTION

A. Background

During April and May 1984, The Field Artillery Board, Ft. Sill, OK conducted a Force Development Testing and Experimentation (FDT&E) of the Fire Support Team Headquarters (FIST HQ) concept at Ft. Riley, KS. The test consisted of three iterations of a 120-hour Scenario Oriented Recurring Evaluation System (SCORES) field exercise that was based upon and included mechanized infantry and armor defensive maneuvers. The task force was confronted by an opposing force (OPFOR) of various strengths and a jamming team. All elements were strictly controlled by the test directorate during the first two exercises. The third exercise was an uncontrolled force on force exercise.

Personnel from the Ballistic Research Laboratory (BRL) designed the experiment to address a subset of the overall objectives and assisted in the implementation of experimental design methodology in the controlled segment of the test. In addition, personnel from the BRL were responsible for designing, coding and testing a new automatic data recording and reduction system based on the Artillery Control Environment (ACE) technology. This report will focus on the experimental design, data reduction and recording methodology, the methods of analysis employed and a brief discussion of the results. The analysis for this report is based upon (1) data obtained from the Field Artillery Board, Ft. Sill, OK, and (2) digital data reduced by BRL and HEL personnel.

B. Purpose

The overall purpose of the FDT&E was to evaluate the operational effectiveness of the FIST HQ equipped with a fire support team vehicle (FIST V) and digital communications. Test results will be used by the United States Army Field Artillery School (USAFAS) to further develop FIST operational and organizational concepts.

To demonstrate this effectiveness, a study of the FIST HQ ability to perform fire support coordination under two modes of forward observer (FO) control, four types of FIST HQ configuration, and thirteen various workload components was conducted.

II. TEST CONCEPT

A. Objectives

1) To determine if the FIST DMD message mode, used for control of the FO's, has an effect on the FIST HQ ability to perform fire support coordination. The message modes tested were the *review* and *automatic* communication modes.

2) To determine if the FIST HQ can perform fire support coordination: a) with the Ground/Vehicle Laser Location Designator (G/VLLD) mounted on the FIST V with all FIST personnel present, b) with the G/VLLD mounted without the FIST Chief present, c) inside the FIST V in a buttoned-up environment and d)

with the G/VLLD dismounted from the FIST V. To dismount the G/VLLD from the FIST V, two FIST HQ personnel must dismount both the G/VLLD and its associated equipment.

3) To determine if mission workload affects the FIST HQ performance of fire support coordination. Mission workload was defined as the number and types of missions the FIST HQ was required to process simultaneously. There were four fire mission types: FIST HQ initiated Copperhead Missions, FIST HQ initiated conventional missions, mechanized infantry FO initiated conventional missions using digital message devices (DMD), and armor platoon leader (Armor) initiated conventional missions using voice.

B. Measures of Performance

A measure of performance (MOP) is a response that is used to quantify the effects of the factors to be evaluated. For FIST HQ initiated missions, it was defined as the elapsed time from target acquisition until the (fire request) message is transmitted from the FIST Digital Message Device (DMD). Service time for armor missions was the time from receipt of a voice fire request message at the FIST HQ until its digital transmission. The time to service FO missions was the elapsed time from when the acknowledgment (ACK) is sent back to the FO from the FIST DMD, indicating receipt of a fire request message until the message is retransmitted. This indicates the time a message spends in the FIST DMD message queue combined with the processing and decision time of the FIST HQ.

C. Scope

The first two field exercises (FEX 1, FEX 2), which were a combination of Live Fire and Force on Force, utilized three FIST HQ and one Combat Observation Lasing Team (COLT) attached to a mechanized infantry task force that consisted of two mechanized infantry companies and one armor company. (See Figure 1).

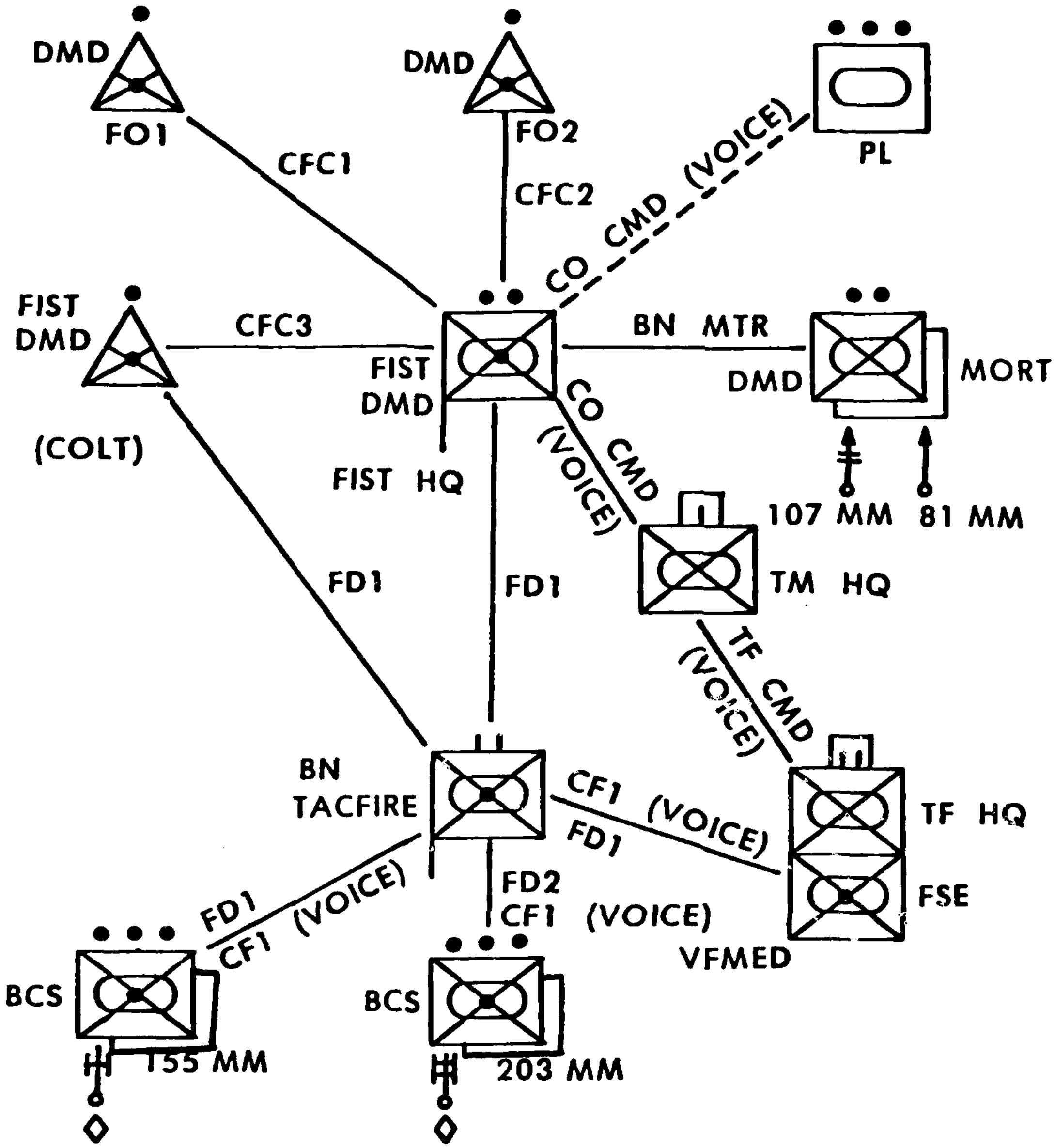
The FIST HQ consisted of:

1. The Fire Support Team Chief

2. The Fire Support Team Sergeant

3. Two radio telephone operators

All members of the FIST HQ were trained in the operation of the FIST DMD. Nine weeks of individual training was conducted and validated by the USAFAS. This individual training was followed by two weeks of collective training.



COMPANY FIRE CONTROL NET (CFC)
BATTALION MORTAR FIRE DIRECTION NET (BN MTR)
FIELD ARTILLERY COMMAND FIRE NETS (CF1, CF2)
FIELD ARTILLERY FIRE DIRECTION NETS (FD1 FD2)
COMPANY COMMAND NET (CO CMD)
TASK FORCE COMMAND NET (TF CMD)

NOTE: THE TF WAS COMPOSED OF THREE SIMILARLY ORGANIZED COMPANY TEAMS

Figure 1. Fire Support Structure.

D. Limitations

1) After receiving the initial fire request message from a FO and deciding how the fire request should be handled, the FIST HQ routed all subsequent messages for that fire mission (through the FIST DMD) in the automatic "mission mode." That is, all subsequent messages for that fire mission were automatically routed to the selected fire support asset through the FIST DMD. Operator intervention was needed only if a message did not get acknowledged within four transmissions.

2) Electronic Warfare was prohibited during the controlled portion of the FDT&E.

3) Range regulations at Fort Riley prevented the G/VLLD from being employed in a totally realistic environment. Laser designation and range finding were allowed in only two locations and, even then, had to be restricted.

4) The control cells that contained the buttoned-up configuration were run at night.

E. Data Collection

In addition to manual data collection methods employing human observers to record test data, a new automatic data recording technique based on the ACE technology was used for the first time in a field exercise. The procedure consisted of recording digital radio traffic, together with a time code, on analog magnetic tape. Every 24 hours the tapes were shipped to Aberdeen Proving Ground (APG), MD where HEL personnel received the tapes and played them back to digitize and insert the message data into the computer using the message collection and reduction system. The sorted list of messages was then written to digital magnetic tapes and shipped to Ft. Sill for analysis.

III. MESSAGE COLLECTION AND REDUCTION SYSTEM

The major components of the message collection and reduction system were

1) Bit Boxes (Tactical Communication Modems, TCM)

2) VAX 11/750 Computer

3) BRL VAX Unix Operating System

4) BRL Message collection and reduction software

A. Hardware

Bit Boxes are microprocessor based modems which enable Tactical Fire Direction System (TACFIRE) hardware to communicate with commercial computers. The Bit Boxes convert Frequency Shift Keyed (FSK) variable format and fixed format TACFIRE messages (from wire line or radio) to RS232 ASCII character format which commercial computers can accept, and visa versa.

A DEC VAX 11/750 computer was available for use as the main computer to support the message collection and reduction software. The computer operating system was a BRL enhanced version of 4.2 BSD (Berkley System Distribution) Unix.

B. Software

The application software, which was written in the C programming language, had two primary tasks: 1) message collection, and 2) message reduction.

The message collection program receives streams of characters from the Bit Boxes, separates the streams into complete messages, records the start and end time of each message, and stores this information in a computer file.

The data reduction program reads the data files created by the message collection program and sorts the messages by fire mission. The result is three other files that contain (1) a list of messages categorized by fire mission target number, (2) a list of unknown messages, and (3) a list of messages that are known but not part of a fire mission. These lists of messages were shipped to Ft. Sill and combined with manual data to create a comprehensive data base for analysis. For an indepth description of the message collection and reduction system see "Field Artillery Digital Message Collection and Reduction Software," BRL-IMR-822, June 1984.

IV. EXPERIMENTAL DESIGN

A. Factors

The three factors that were tested during the controlled portion of the FDT&E were FIST Configuration, Mode of FIST DMD Control and Mission Workload.

1) FIST Employment Configuration alternatives were:

a) G/VLLD mounted - all hatches on the FIST V were open and the G/VLLD was mounted with the entire FIST HQ present.

b) G/VLLD mounted without FIST Chief - all hatches on the FIST V were open and the G/VLLD was mounted with the FIST Chief absent.

c) G/VLLD dismounted - the G/VLLD was displaced from the vehicle along with two of the four FIST HQ members.

d) Buttoned-Up - all hatches on the FIST V were closed and the G/VLLD was mounted with the entire FIST HQ present.

2) Mode of FIST DMD Control

a) Review - FIST DMD stops all initial fire request messages from platoon FO's for the FIST HQ to review.

b) Automatic - FIST DMD automatically forwards all initial fire request messages without action by the FIST HQ.

3) Mission Workload

Mission workload was defined as the number and types of fire missions the FIST HQ were required to process simultaneously. The four types of fire missions were:

1) CONV - FIST HQ shooting a conventional munition

2) CPH - FIST HQ shooting a Copperhead munition

3) ARMOR - Missions initiated by voice from the armor platoon leader and converted to a digital message at the FIST HQ.

4) FO - Missions initiated by the mechanized infantry FO and transmitted digitally to the FIST HQ.

Based on seven combinations of mission types processed simultaneously, thirteen components of mission workloads were defined as shown in Table 1.

B. Design Matrix

It was decided that the smallest period of time reasonable to test any one of the treatment combinations was two hours. A factorial design was constructed with each experimental combination being tested in a random order. This scheme assured that the effect of each of the experimental combinations on the FIST HQ ability to perform fire support coordination could be measured. The FIST HQ were tested under all of the experimental combinations and the design was repeated for each of the two controlled iterations of the FDT&E. The design matrix is presented in Table 2.

TABLE 1. MISSION WORKLOAD COMPONENTS

COMPONENTS	FIRE MISSIONS PROCESSED SIMULTANEOUSLY	MISSION TYPE
a	1 CPH	CPH
b	1 FO + 1 CONV	CONV
c	1 FO + 1 CONV	FO
d	1 ARMOR + 1 CONV	CONV
e	1 ARMOR + 1 CONV	ARMOR
f	1 FO + 1 CPH	CPH
g	1 FO + 1 CPH	FO
h	1 FO + 1 ARMOR + 1 CPH	CPH
i	1 FO + 1 ARMOR + 1 CPH	ARMOR
j	1 FO + 1 ARMOR + 1 CPH	FO
k	2 FOs	FO
l	1 ARMOR + 2 FOs	FO
m	1 ARMOR + 2 FOs	ARMOR

V. STATISTICAL ANALYSIS

The analysis for this section is based on data obtained from the Field Artillery Board, Ft. Sill, OK, which was a combination of manual data collected by human observers and digital data that was reduced by the message collection and reduction system. This section is intended to be a supplement to the data analysis conducted by the Field Artillery Board and focuses on several key factors and their associated levels. Unfortunately, the buttoned-up level of the FIST Employment Configuration factor was not available in this subset of the FDT&E data base, but will be analyzed in the next section which focuses on the digital data that was reduced by the BRL/HEL message collection and reduction system.

A. Transformation

As the data was being checked for completeness, it was noted that the distribution of service time was skewed and that the variances of the observations under various experimental conditions were different. Further investigation of the data revealed a positive correlation between the cell standard deviations and the cell means. Correlation between the standard deviations and cell means is often accompanied by marked non-normality and non-homogeneity of variance and indicates that the particular form of the original observations is unsuitable for Analysis of Variance (ANOVA) procedures.

However, a transformation can be determined which makes the standard deviation independent of the mean, corrects non-homogeneity and also results in the observations being distributed more normally. In general, if a significant functional relationship between the standard deviations and the group means can be determined, then the transformation is the integral of the reciprocal of this functional relationship. Using this

TABLE 2. DESIGN MATRIX

MISSION WORKLOAD COMPONENTS		REVIEW MODE				AUTOMATIC MODE			
		WO CHIEF MNTD	100% FIST MNTD	100% FIST BUTTONED UP	100% FIST DMNTD	WO CHIEF MNTD	100% FIST MNTD	100% FIST BUTTONED UP	100% FIST DMNTD
1 CHD	CHD								
1 FO + 1 CONV	CONV								
1 FO + 1 CONV	FO								
1 ARMOR + 1 CONV	CONV								
1 ARMOR + 1 CONV	ARMOR								
1 FO + 1 CHD	CHD								
1 FO + 1 CHD	FO								
1 FO + 1 ARMOR + 1 CHD	CHD								
1 FO + 1 ARMOR + 1 CHD	ARMOR								
1 FO + ARMOR + CHD	FO								
2 FOs	FO								
1 ARMOR + 2FOs	FO								
1 ARMOR + 2 FOs	ARMOR								

procedure, the following transformation was developed:

1.7 ln (18.9 + .56 (service time))

The transformed data were more normal and the variances among the experimental conditions were more homogeneous.

B. Analysis Of Variance

An analysis of variance procedure was performed on the transformed data with one slight modification to this procedure due to unequal experimental group sizes. The sum of squares for all terms in the model, except the error term, was weighted by the harmonic mean. The ANOVA is presented in Table 3. A star next to the F-ratio indicates that the factor is significant at the alpha level of .05. Since this analysis assumes a fixed effects model, the denominator for all F-ratios is the pooled error term.

TABLE 3. ANALYSIS OF VARIANCE
(SERVICE TIME)

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F RATIO
Mission Workload	12	101.00	8.42	10.60*
Mode	1	5.65	5.65	7.14*
Configuration	2	0.025	0.01	< 1
Mission Workload x Mode	12	9.21	0.77	< 1
Mission Workload x Configuration	24	13.43	0.56	< 1
Configuration x Mode	2	0.08	0.04	< 1
Mission Workload x Mode x Configuration	24	12.33	0.51	< 1
Pooled Error	461	365.90	0.79	

Since the ANOVA was performed on the transformed data, it was decided that comparisons of medians, calculated on observed service times, would be more meaningful than comparing transformed means.

C. Results

The most significant term in the analysis was mission workload. One reason for this significance is that it took substantially less time to service fire request messages from mechanized infantry FO missions than either the FIST HQ missions (Copperhead or Conventional) or Armor missions. In both FIST DMD control modes, the FIST HQ initiated fire request messages require data input, review, and transmittal. Armor messages, which are received by voice, must be reviewed and input as digital messages by the FIST HQ; whereas the digital FO fire requests require only review and transmittal in the review mode of FO control, and no processing in the automatic mode.

Another interesting result was that in mission combinations involving Armor missions, the Armor missions had a longer service time than any other mission type. This trend seems to indicate that it takes the FIST HQ longer to process voice initiated fire request messages than to initiate his own or service FO missions. This result is not surprising since it takes longer to input a message manually than to receive one digitally. These trends were consistent in both the Automatic and Review modes as shown in Table 4.

The number of missions processed simultaneously also affected FIST HQ service time. In plotting the median service time for the mechanized infantry FO fire missions in review mode (See Figure 2), one can see that it takes the FIST HQ longer to service FO missions when it is also initiating a Copperhead mission and receiving a armor message than when it is just servicing FO missions and shooting Copperhead. In addition, the FIST HQ service time for FO fire request messages is shorter when it is also initiating a conventional mission as opposed to also shooting Copperhead. This result is not surprising. When the FIST HQ is initiating a Copperhead mission while in the review mode, the FIST DMD operator functions are disabled after sending a FO Command (Fire) or a Quick Fire message and no action can be taken by the FIST DMD operator until the X button is pressed to end the Copperhead mission. The FIST HQ spent the longest time servicing mechanized infantry FO missions in review mode, when they were not initiating or reviewing any other mission types. In this mission workload (2-FOs), the FIST HQ only responsibility was to review the two messages received from his mechanized infantry FOs. FIST personnel spent a lot of time reviewing, changing, and deciding if the initial fire request message should be sent to TACFIRE or to one of their local resources, such as the battalion mortar platoon.

From Figure 3, one can see that it took more time for the FIST HQ to service armor messages when they were also shooting a Copperhead or conventional mission than when they were only reviewing a mechanized infantry FO messages and serving armor missions. This trend is consistent with both the automatic and review FIST DMD control mode.

In the automatic control mode, all initial fire request messages received by the FIST HQ are automatically forwarded to their destination. Messages initiated in the review mode must be passed by the FIST DMD operator before they can be transmitted. Therefore, one could expect the FIST DMD mode of control to significantly affect the

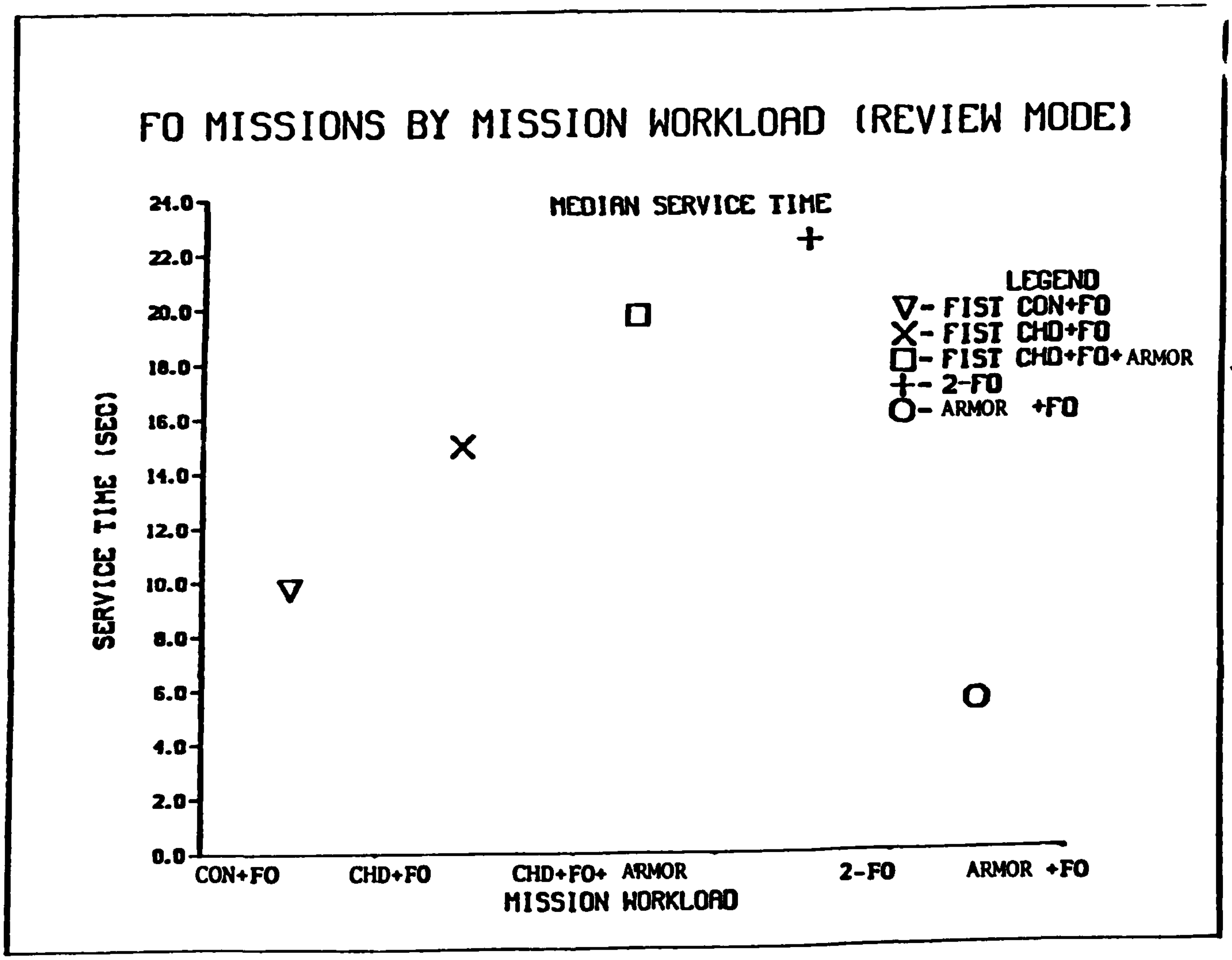


Figure 2. Median Service Time for Mechanized Infantry FO Initiated Messages by Workload.

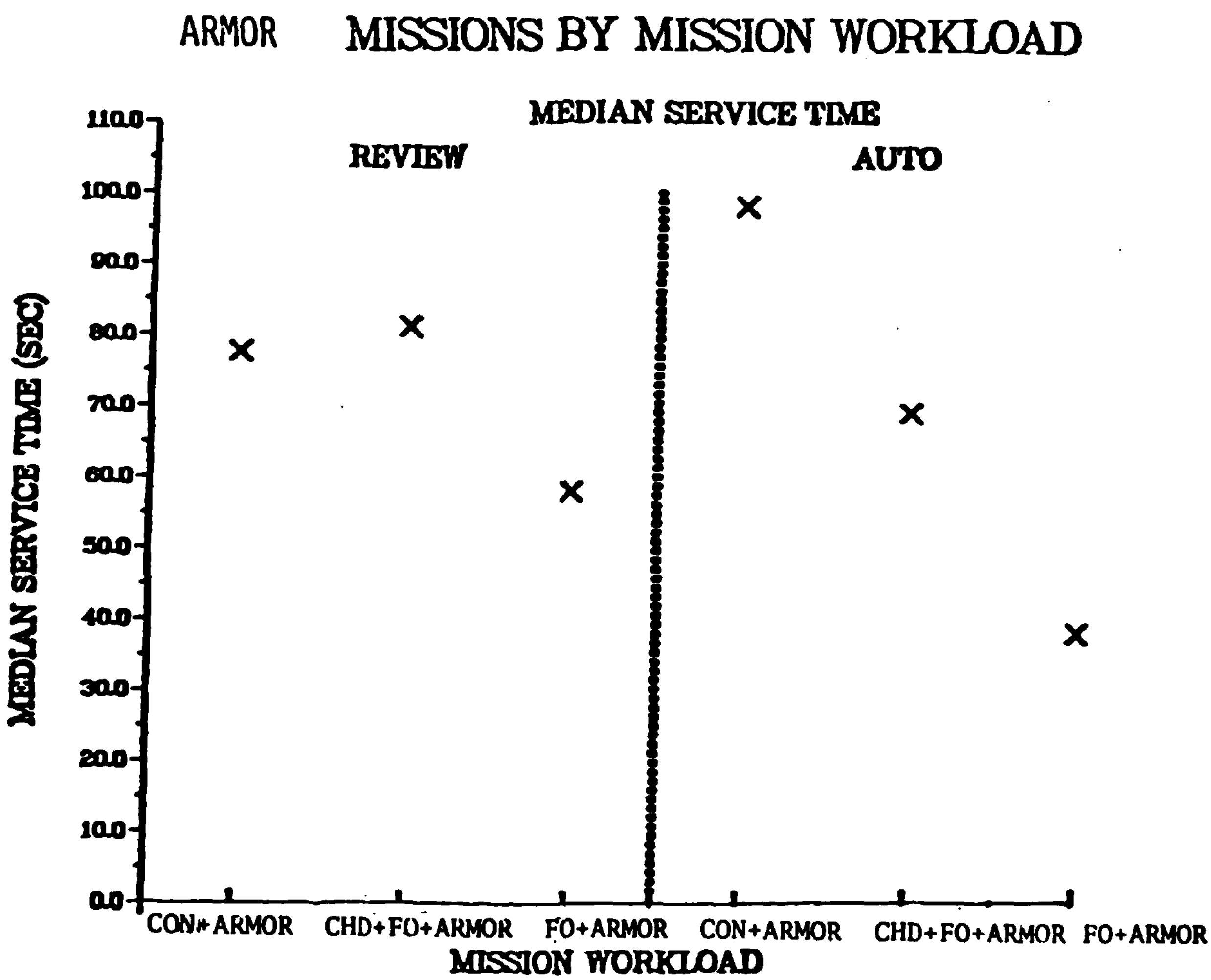


Figure 3. Median Service Time for Armor Initiated Messages by Workload.

TABLE 4. MISSION WORKLOAD BY MODE
(MEDIAN SERVICE TIME)
(SECONDS)

FIRE MISSION TYPE	MISSION WORKLOAD	Mode	
		Review	Auto
CPH	CPH	55	35
CPH	FO + CPH	11	44
CPH	FO + ARMOR + CPH	6	34
CONV	FO + CONV	58	76
CONV	ARMOR + CONV	77	74
FO	FO + CONV	10	2
FO	FO + CPH	15	2
FO	FO + ARMOR + CPH	20	2
FO	2 FOs	22	2
FO	2 FOs + ARMOR	5	2
ARMOR	ARMOR + CONV	79	98
ARMOR	FO + ARMOR + CPH	81	69
ARMOR	ARMOR + 2 FOs	58	37

time it takes to service digital fire request messages. The ANOVA table revealed that the Mode of FIST DMD Control was significant.

The percent of all messages processed by service time in the automatic and review modes are shown in Figures 4 and 5, respectively. The median service time for the automatic mode was small, 7.0 seconds, when compared to the median service time of 29.0 seconds to service messages in the review mode. For mechanized infantry FO missions, the median service time in the review mode ranged between 5.0 and 22.0 seconds over all workloads. However, in the automatic mode, the median service time

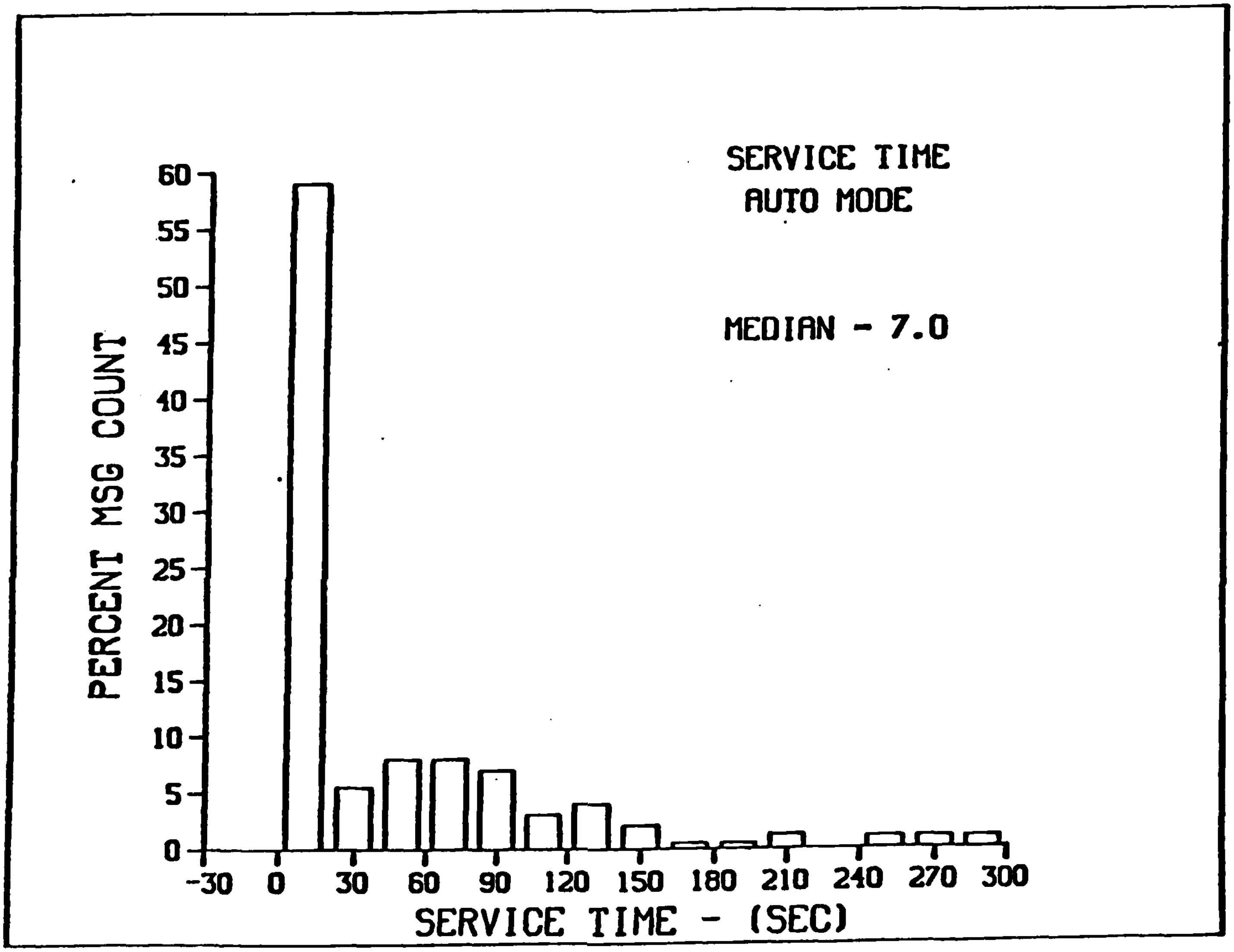


Figure 4. Percent of Messages Processed, by Median Service Time, in Automatic Mode.

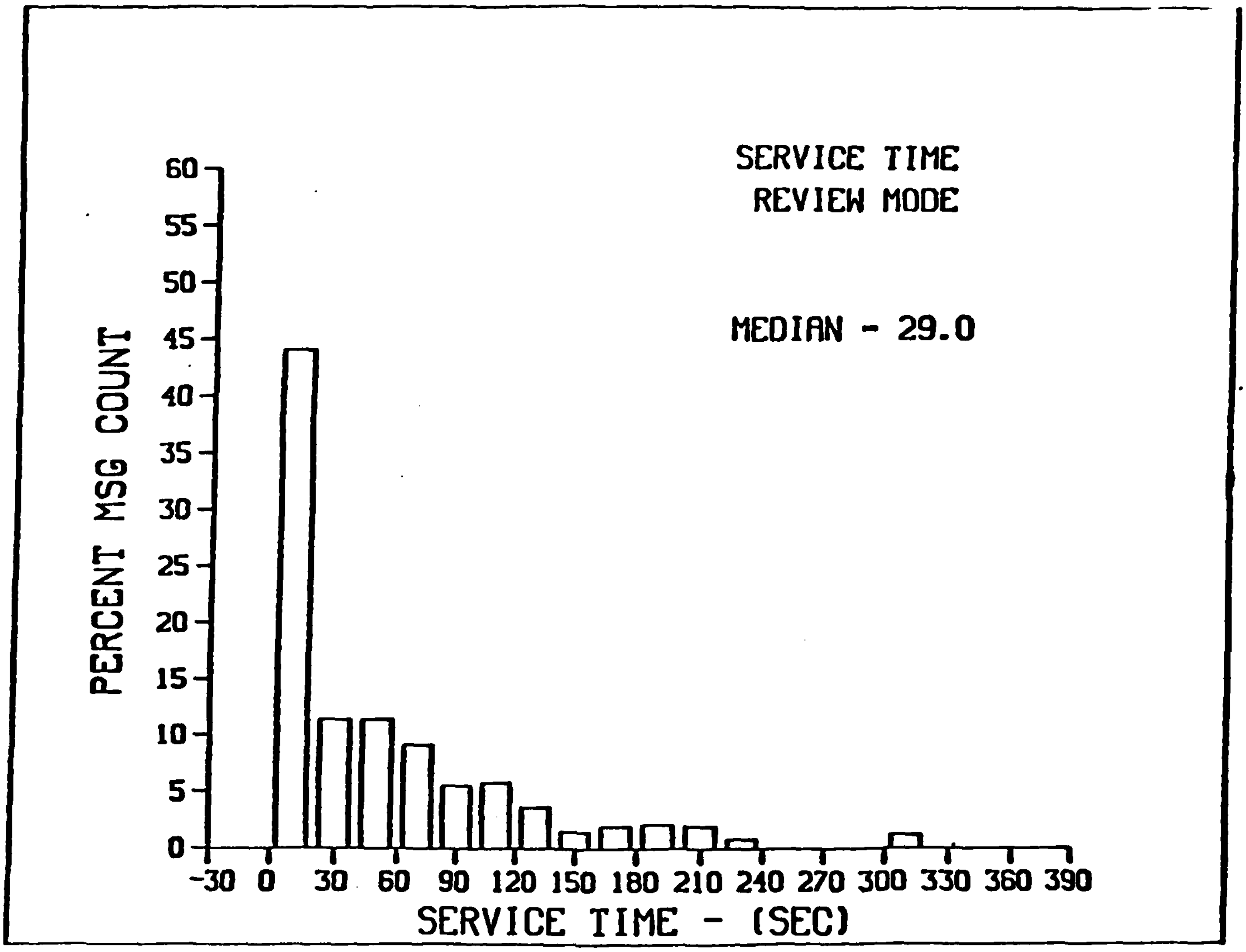


Figure 5. Percent of Messages Processed, by Median Service Time, in Review Mode.

for all workloads was 2.0 seconds. This trend was not as prevalent for messages initiated by the FIST HQ or messages received by voice from the armor as depicted in Table 4.

It is worth noting that FIST Employment Configuration was not statistically significant. The FIST's ability to service FO and ARMOR missions as well as initiate his own missions was not affected by the various configurations. This implies that the FIST can perform timely fire support coordination when the FIST Chief is not present or when two members of the FIST are not available (due to the G/VLLD being dismounted). However, this infers nothing about the quality of the decision being made.

One puzzling result was that the median service time for a FIST HQ to service Copperhead missions while in review mode and for mission workload (FO + ARMOR + CPH) was only 6.0 seconds and only 11.0 seconds for workload (FIST FO + CPH). Looking at the service time distribution for these two categories, one notes a bimodal distribution which may indicate the presence of a lurking variable. A lurking variable affects the outcome of an experiment, but is unknown to the experimenter and unaccounted for in the design.

Cluster analysis was used to try to categorize the Copperhead missions into two groups: This is a multivariate statistical technique in which Copperhead missions were separated into groups based on the maximization of variance within groups and the minimization of the distance between groups. A difference in values among groups from different Copperhead missions is said to exist if the hypothesis of equality of means among groups is rejected by an F-test with a significance level of .05. The number of groups in which to categorize the Copperhead missions was not specified.

Using cluster analysis on the Copperhead mission service time, two populations were identified. One group had a median service time of 8.0 seconds and a range between 1.0 and 32.0 seconds. The other group centered at 56.0 seconds and ranged between 34.0 and 190.0 seconds. The groups were statistically different at a significance level of .05. Based on the above categorization scheme, the analysis was redone with the two groups of Copperhead missions. This resulted in workload having sixteen categories. The conclusions remained unchanged from the original analysis. Mission Workload and Mode of FIST DMD Control were the only factors determined to significantly affect FIST service time and this significance can be contributed to the influence these two factors had on the FIST servicing of FO and Armor missions.

The median service time for the two groups of Copperhead missions by Mode of FIST DMD Control and Mission Workload are given in Table 5. The median service time for the group with the smaller median service time ranged between 6.0 and 9.0 seconds while the second group ranged between 45.0 and 92.0 seconds. No statistical differences were found between the review and automatic modes of FIST DMD Control for either group. Similarly, Mission Workload had no effect on either group of Copperhead missions.

There are several possible reasons as to why there are two categories of Copperhead mission service time. One reason is that terrain conditions will strongly influence Copperhead service time. Another reason is that there are two types of Copperhead missions (priority and target of opportunity) and the data from Ft. Sill did not categorize these two types. Priority Copperhead missions are preplanned missions with preassigned targets. The mission data is stored until the target appears; the mission is then reactivated and carried to its conclusion. A target of opportunity mission is not a planned mission but occurs when a target appears at an opportune time and place. Target of opportunity missions require a longer processing time by the FIST than priority Copperhead missions starting at target acquisition.

TABLE 5. Copperhead MISSIONS
(REVIEW & AUTOMATIC)
(MEDIAN SERVICE TIME)

MODE	MISSION WORKLOAD	GROUP 1	GROUP 2
REVIEW	CPH	7.0	73.0
	FO + CPH	7.0	92.0
	FO + ARMOR +CPH	6.0	45.0
AUTOMATIC	CPH	7.0	68.5
	FO + CPH	8.0	70.0
	FO + ARMOR + CPH	9.0	66.0

VI. STATISTICAL ANALYSIS II - DIGITAL DATA

The analysis for this section is based solely on FIST service times of FO initiated missions obtained from the digital data that was collected and reduced. The purpose of this analysis is to validate the digital data base for modeling purposes. If similar results are obtained from both the digital and digital/manual data bases then confidence in the validity of these results is gained. In addition, different types of messages were added to this analysis to assist the modeling effort currently being conducted.

A. Factors

Due to the nature of the data, service times for FIST initiated missions and Armor missions can not be extracted as target acquisition time and can not be obtained through automatic, digital means. Only FO initiated mission service times were available. Consequently, Mission Workload was eliminated from the model used to analyze this data. However, based on the schedule of controlled cells played during FEX 1 and FEX 2, the two levels of FIST DMD Mode of Control and the four levels of FIST Employment Configuration were available. In addition, a new factor called Message Type was added. This factor consisted of Fire Request messages (FRs), Artillery Target Intelligence messages (ATIs) and End-of-Mission messages (EOMs).

Message Type consisted of:

1) Fire requests are messages that initiate a fire missions. A fire request can either be a FR GRID or FR POLAR. Since the FIST DMD automatically converts polar data to grid data, there is no need to separate these two type of initiating messages in analyzing the FIST service time. In checking this assertion, the hypothesis that the two types of missions are the same with respect to service time was not rejected.

2) Artillery Target Intelligence messages contain intelligence information. This message, unlike a fire request, will not initiate fire mission processing at the BN FDC.

3) End-of-Mission messages which are sent by the FO to indicate completion of the fire mission.

Message-To-Observer (MTO) messages could also be considered a level of this factor. However, FIST service times for MTOs were not utilized in this analysis since MTO service times were less than or equal to one second in almost all instances.

B. Modified Design Matrix

This analysis was based on a 4 x 3 x 2 factorial design. The main effect and all one and two-way treatment combinations could be tested using this model. The modified design matrix for this analysis is presented in Table 6.

C. Transformation

Like the digital/manual data, the distribution of the digital service time data was also skewed and the variances of the observations under various experimental conditions were different. A positive correlation was observed between the standard deviations and the cell means. Using the procedure outlined in the previous section, the following transformation was developed:

$$.67 \ln (.34 + 1.5 \text{ (service time)})$$

The assumptions of normality and homogeneity of variance among the experimental conditions for the transformed data could not be rejected. Bartlett's test statistic was calculated as 1.02 which is not significant at a significance level of .05.

TABLE 6. DESIGN MATRIX

	MODE							
	REVIEW				AUTO			
	CONFIGURATION				CONFIGURATION			
MESSAGE TYPE	WO CHIEF MNTD	100% FIST MNTD	100% FIST BUTTONED UP	100% FIST DMNTD	WO CHIEF MNTD	100% FIST BUTTONED UP	100% FIST MNTD	100% FIST DMNTD
Fire Requests								
ATIs								
EOMs								

VII. RESULTS

An analysis of variance procedure was performed on the transformed data using the weighting techniques previously described to adjust for unequal experimental cell sizes. Since the model analyzed was a fixed effects model, the mean square of each treatment combination was divided by the pooled error mean square. The ANOVA table is presented in Table 7.

TABLE 7. ANALYSIS OF VARIANCE (SERVICE TIME)

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F RATIO
Message Type	37.77	2	18.89	13.53*
Configuration	1.07	3	.36	< 1
Mode	15.85	1	15.85	11.36*
Message Type x Configuration	23.75	6	3.96	2.83*
Message Type x Mode	18.00	2	9.00	6.45*
Configuration x Mode	8.67	3	2.89	2.07
Message Type x Mode x Configuration	17.77	6	2.96	2.12
Pooled Error	728.45	522	1.40	

Message Type had the greatest influence on the FIST service time. As shown in Table 8, the median service times for fire requests and artillery target intelligence messages were substantially different from that for end-of-messages in the FO review mode. This difference can be attributed to how the FIST DMD handled these types of messages. Fire requests and ATIs had to be reviewed, recorded and verified by the FIST HQ in the review mode of FO control before they could be transmitted to their final destination. End-of-mission are subsequent messages and the FIST HQ routed all subsequent messages for a fire mission through the FIST DMD in the automatic mission mode. Therefore, EOMs required no review by the FIST. It is this difference in the handling of the different types of messages that accounts for a significant Message Type/Mode interaction. No significant difference among the median service times of the three types of messages could be detected in the automatic mode. The median service time for all three types ranged between 1.0 and 4.0 seconds.

TABLE 8. MESSAGE TYPE BY MODE
MEDIAN SERVICE TIME
(SECONDS)

MESSAGE TYPE	REVIEW	AUTOMATIC	TOTAL
Fire Requests	25.0	4.0	8.0
ATIs	22.5	1.0	3.5
EOMs	1.5	2.0	2.0

Fire request messages required a longer FIST service time in both modes of FO control than ATI messages. Although fire requests have a higher priority than ATIs, they contain more critical information that has to be processed by the FIST. Therefore, it was not surprising that the median service time for fire requests was slightly higher than the median service time for ATIs.

Mode of FIST DMD Control was also a significant source of variability. Fire requests and ATIs took between 22.5 and 25.0 seconds to process in review mode and only between 1.0 and 4.0 seconds in the automatic mode.

One surprising result was that the Message Type and FIST Employment Configuration combinations were significant. This can be contributed to fire requests that were processed in a buttoned-up environment. The FIST took substantially longer (median service time of 38.0 seconds) to service fire request messages in a buttoned-up configuration at night than any other Message Type/Configuration combination as shown in Table 9 and Figure 6. This trend was consistent in both auto and review mode of FIST DMD control as shown in Table 10.

VIII. CONCLUSIONS

Based on the results of the analysis of the limited database obtained from the Field Artillery Board, the FIST HQ demonstrated its ability to perform fire support coordination. The FIST HQ ability to service fire missions was not affected by different FIST HQ configurations. The FIST did perform timely fire support coordination at the same rate when the FIST Chief was not present and when two members of the FIST were not available because the G/VLLD was dismounted. Although Mission Workload and Mode of FO Control were significant, the largest median service time observed was only 98.0 seconds. This occurred when the FIST HQ had to input the voice messages from the Armor.

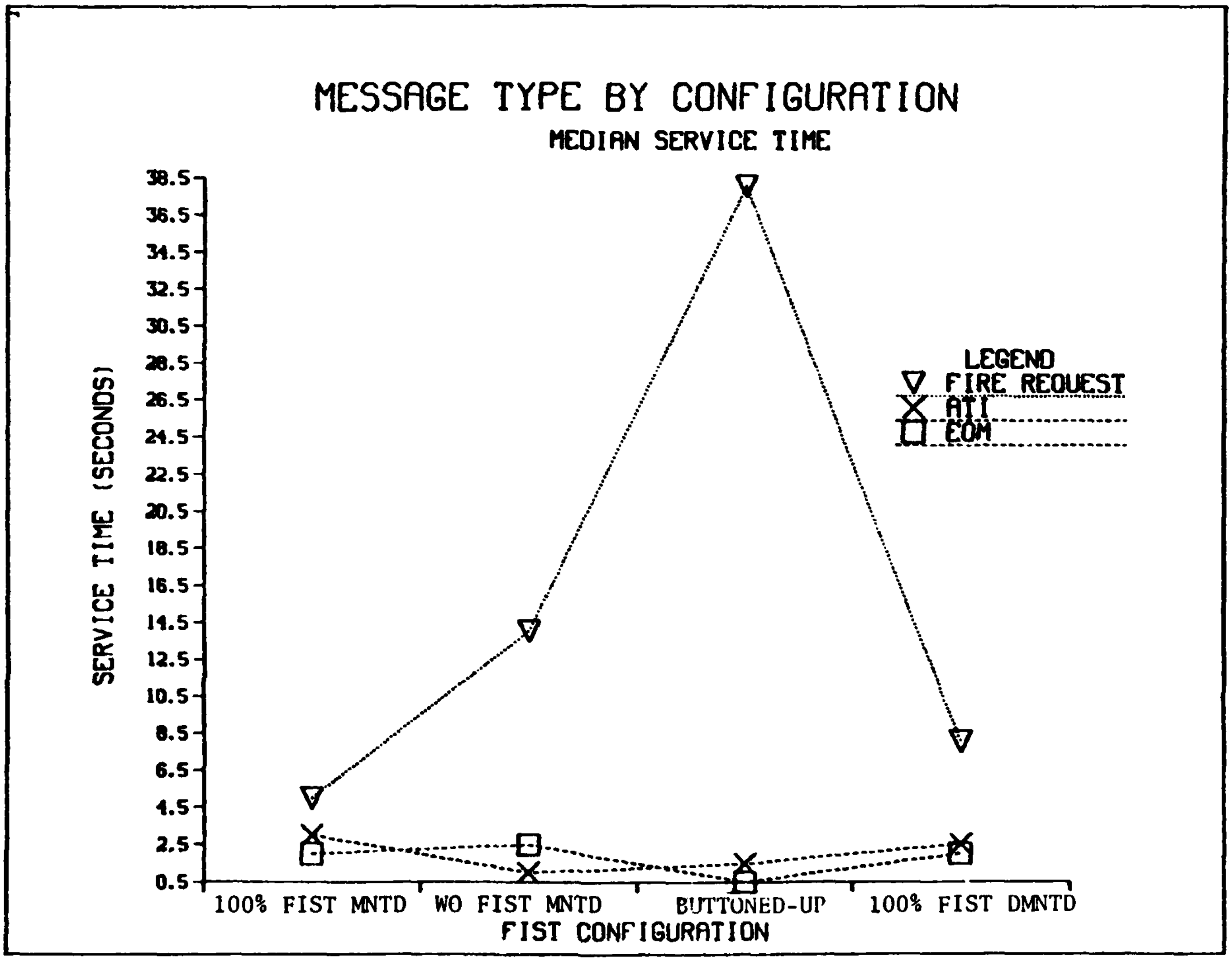


Figure 6. Median Service Time for Message Type by Configuration.

TABLE 9. MESSAGE TYPE BY CONFIGURATION
(MEDIAN SERVICE TIME)
(SECONDS)

MESSAGE TYPE	CONFIGURATION 100% FIST MNTD	WO FIST MNTD	100% FIST BUTTONED UP	100% FIST DMNTD
Fire Requests	5.0	14.0	38.0	8.0
ATIs	3.0	1.0	1.5	2.5
EOMs	2.0	2.5	.5	2.0

TABLE 10. FIST DMD CONTROL BY CONFIGURATION
(MEDIAN SERVICE TIME)
(SECONDS)

FIST DMD CONTROL	CONFIGURATION 100% FIST MNTD	WO FIST MNTD	100% FIST BUTTONED UP	100% FIST DMNTD
Review	27.0	22.5	32.0	20.0
Automatic	3.0	3.0	8.0	4.0

The number and types of missions processed simultaneously influenced the FIST HQ ability to service FO and Armor missions. However, Mission Workload did not affect the two types of Copperhead missions that were categorized using cluster analysis. Based on this statistical technique, Copperhead missions were shown to not be affected by the FIST DMD mode of control. In fact, FIST DMD mode of control only affected the mechanized infantry FO missions.

The digital data analysis confirmed the results obtained from analyzing the manual digital data. The FIST HQ ability to service FO missions was not affected by having the G/VLLD mounted either with or without the FIST Chief present or with the G/VLLD dismounted. The mode of FO control also had a similar effect on fire request messages in both data bases. One result found was that the FIST spent a substantially longer time servicing fire requests while in a buttoned-up tactical situation than in any other type of configuration tested.

Finally, the automatic reduction system proved to be a useful tool for data collection and reduction of field data and the ability to perform a controlled experiment during a field test was demonstrated. However, it also demonstrates the need for more sophisticated MOP's than simply speed of service.

IX. ACKNOWLEDGEMENTS

The authors wish to express their appreciation to The Fire Support and Target Acquisition Directorate of the HEL, The Artillery Systems Concepts Branch of the BRL and to Annette Wiseman for formatting this report.

NOMENCLATURE

ACE	Artillery Control Environment
ACK	Acknowledgement (message)
ADP	Automatic Data Processing
ATI	Artillery Target Intelligence
BBP	Bit Box Interface Program
bn	battalion
btry	battery
C^3	Command, Control and Communication
CH	Chief
Cmd	Command
CO	Company
CPU	Central Processing Unit
DMD	Digital Message Device
EOM	End of Mission (Message)
EW	Electronic Warfare
FDT&E	Fire Development Testing and Experimentation
FFE	Fire for Effect (Mission)
FM	Fire Mission
FIST	Fire Support Team
FISTV	FIST Vehicle
FO	Forward Observer
FOSCE	Forward Observer Scenario Program
FR	Fire Request
FR GRID	Call to Fire using Grid Coordinates for Target Location
FSE	Fire Support Element
FSK	Frequency Shift Keying
GDU	Gun Display Unit
HQ	Headquarters
LT	Lieutenant
MOP	Measure of Performance
MSG	Message
MTO	Message to Observer (Message)
RDT&E	Research, Development, Testing and Evaluation
SCORES	Scenario Oriented Recurring Evaluation System
TACFIRE	Tactical Fire Direction System
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